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10/19/00

**Identification of Prior Complete Application**

SC/Serial No.: 09/009/369

Art Unit: 1765

Filed: January 20, 1998

Examiner: Umez Eronini, L.

Title: METHOD FOR USING A HARD MASK FOR CRITICAL DIMENSION GROWTH CONTAINMENT

Inventor(s): Stephen P. DeOrnellas, et al.

**Delete the Following Inventor(s) for This Application:** (none)

**Declaration**

☒

A copy of the Declaration (signed by all inventors) and the Prior Complete Application and Figures are submitted herewith.

**Amendments**

\_\_\_\_\_

Please CANCEL in this application original claims\_\_\_\_\_ of the prior complete application before calculating the filing fee. (At least one original independent claim must be retained for filing purposes.) However, if this instruction results in cancellation of all original claims, please instead retain the lowest numbered original claim.

☒

Please AMEND the specification by inserting before the first line of the application: "This application is a continuation of Serial No.09/009,369, filed January 20, 1998."

☒

A preliminary amendment is enclosed. Please enter the preliminary amendment before calculating the application filing fee. (Claims added must be consecutively numbered beginning with next number after highest number in prior complete application.)

**Petition for Extension of Time to Respond**

\_\_\_\_\_

No extension of time is required for the prior complete application.

\_\_\_\_\_

Pursuant to 37 C.F.R. § 1.136(a), enclosed is a petition for an extension of time for the prior complete application, up to and including today, for responding to the Office action together with the fee set by 37 C.F.R. § 1.17.

**Power of Attorney**

☒

A power of attorney appears in the prior complete application.

\_\_\_\_\_

A new power of attorney is submitted herewith.

### Assignment

✓

The prior application is assigned of record to:

Tegal Corporation

An assignment of the invention to:

   is submitted herewith,  
together with an ASSIGNMENT RECORDATION FORM COVER SHEET  
and recordal fee of \$40.00.

### Claim of Priority

Priority of foreign application Serial No.         , filed on                 ,  
in                  is claimed under 35 U.S.C. § 1.119.

The certified copy was filed in prior U.S. application Serial No.         ,  
filed         .

### Small Entity Statement

Statement(s) claiming small entity status is (are) submitted herewith.

✓

Statement(s) claiming small entity status was filed in the parent  
application Serial No. 09/009,369, on August 17, 1998 and its benefit  
under 37 C.F.R. § 1.28(a) is hereby claimed.

### Also Enclosed Are:

An Information Disclosure Statement under 37 C.F.R. § 1.56.

## Filing Fee

The continuation/divisional patent application filing fee is calculated as shown below:

No. Filed	No. Extra	Rate Small Entity/ Other Than Small Entity		
Basic Fee		\$355.00 \$710.00	=	\$355.00
Total Claims <u>41</u> ** - 20 = <u>21</u> *	X	\$ 9.00 \$ 18.00	=	\$189.00
Independent Claims <u>7</u> ** - 3 = <u>4</u> *	X	\$ 40.00 \$ 80.00	=	\$160.00
First Presentation of Multiple Dependent Claim(s) _____		\$135.00 \$270.00	=	\$0
Total PATENT APPLICATION FILING FEE:				\$704.00

\* If the difference is less than zero, enter "0".

\*\* Count claims after any amendment.

## Method of Payment of Fees

The total fee associated with this communication is calculated as follows:

Patent application filing fee	\$704.00
Net fee for extension of time (See attached petition)	\$
Assignment recordal fee (See attached cover sheet)	\$
TOTAL FEE DUE:	=====
	\$704.00

X A check in the amount of the TOTAL FEE DUE is enclosed.

X The Commissioner is hereby authorized to charge underpayment of any additional fees associated with this communication or credit any overpayment to Deposit Account No. 06-1325. A duplicate copy of this CONTINUATION OR DIVISIONAL APPLICATION TRANSMITTAL LETTER UNDER 37 C.F.R. §1.53(b)(1) form is enclosed.

**Correspondence Address**

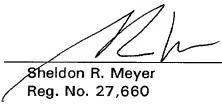
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Respectfully submitted,

Date: 10/19/00

By: 

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

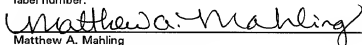
In re Application	)	<u>PATENT APPLICATION</u>
	)	
Inventors: Stephen P. DeOrnellas et al.	)	
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SC/Serial No.: Unknown	)	
	)	<b>Customer No. 23910</b>
Filed: Herewith	)	
	)	
Title: METHOD FOR USING A HARD MASK FOR CRITICAL DIMENSION GROWTH CONTAINMENT	)	
	)	

CERTIFICATE OF MAILING BY "EXPRESS MAIL" UNDER 37 C.F.R. §1.10

"Express Mail" mailing label number: EL622698276US

Date of Mailing: October 19, 2000

I hereby certify that this correspondence is being deposited with the United States Postal Service, utilizing the "Express Mail Post Office to Addressee" service addressed to **Assistant Commissioner for Patents, Washington, DC 20231** and mailed on the above Date of Mailing with the above "Express Mail" mailing label number.

 (Signature)  
Matthew A. Mahling  
Signature Date: October 19, 2000

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents  
Washington, D.C. 20231

Sir:

Preliminary to the examination of the above-referenced continuation case, please amend the claims as follows:

In the Claims:

Please amend the following claims as indicated below. Please add the new claims set forth below. All pending claims are included for completeness.

1. (Amended) A method for [containment of] minimizing critical dimension growth of [a] the width of features located on a workpiece [substrate] including the steps of:

selecting a workpiece [substrate] with a hard mask deposited over a layer to be etched, which hard mask is comprised of a reactive metal [deposited over a layer to be etched]; and

processing the [layer] workpiece in a reactor using an etch step and using the hard mask to minimize critical dimension growth of features on the layer.

2. (Amended) The method of claim 1 wherein:

said selecting step includes selecting a [substrate] workpiece having a hard mask which hard mask comprises of one of titanium, aluminum, and tantalum.

3. The method of claim 1 including the step of:

exposing the hard mask to a stream of oxidizing gas in the reactor prior to or during said etch step.

4. The method of claim 1 including the step of:

exposing the hard mask to an oxidizing stream comprising of one of oxygen, nitrogen, fluorine, boron, and carbon gas, and any combination of oxygen, nitrogen, fluorine, boron, and carbon gas, in the reactor prior to or during said etch step.

5. (Amended) The method of claim 1 wherein :

said selecting step includes selecting a [substrate] workpiece with a lithographic layer covering the hard mask [into the reactor].

6. The method of claim 1 wherein:

said selecting step includes selecting a substrate having a hard mask which is readily oxidizable.

7. The method of claim 1 wherein:

said selecting step includes selecting a substrate with a hard mark, which hard mask is comprised of a metal with a low sputtering yield.

8. The method of claim 1 including the step of:

exposing the hard mask to a stream of oxidizing gas in the reactor prior to or during said etch step in order to oxidize the surface of the hard mask and thereby slow down an etch rate of the hard mask.

9. The method of claim 1 wherein:

said selecting step includes selecting a hard mask (1) on which has been or (2) on which can be developed at least one of an oxide, nitride, fluoride, boride and carbide.

10. The method of claim 1 including the step of:

providing energy to the reactor in order to increase a rate of oxidation of the hard mask in order to slow down the rate of erosion of the hard mask.

11. (Amended) The method of claim 10 wherein :

said step of providing energy causes the substrate in the reactor to be heated to a temperature in the range of from about 80°C to about 300°C.

12. The method of claim 1 including the step of:

oxidizing the hard mask either prior to or during the processing step.

13. (Amended) A method for [containment of] minimizing critical dimension growth of [a] the width of features located on a workpiece [substrate] including the steps of:

selecting a workpiece [substrate] with a hard mask deposited over a layer to be etched, wherein said hard mask has a low sputter yield and a low reactivity to the etch chemistry of an etch process; and

processing the [layer] workpiece in a reactor using the said etch chemistry in order to etch the layer and using the hard mask to minimize critical dimension growth of the width features on the layer.

14. (Amended) The method of claim 13 wherein:

said selecting step includes selecting a [substrate] workpiece wherein said hard mask is comprised of a reactive metal.

15. (Amended) The method of claim 13 wherein:



said selecting step includes selecting a [substrate] workpiece having a hard mask which [is comprising] comprises at least one of titanium, aluminum, tantalum, tungsten, cobalt, and molybdenum.

16. The method of claim 13 including the step of:  
exposing the hard mask to a stream of oxidizing gas in the reactor prior to or during said processing step.

17. The method of claim 13 including the step of:  
exposing the hard mask to a stream consisting of one of oxygen, nitrogen, fluorine, boron, and carbon and any combination of oxygen, nitrogen, fluorine, boron and carbon.

18. (Amended) The method of claim 13 wherein :  
said selecting step includes selecting a [substrate] workpiece with a lithographic layer covering the hard mask.

19. The method of claim 13 wherein:  
said selecting step includes selecting a substrate having a hard mask which is readily oxidizable.

20. The method of claim 13 including the step of:  
exposing the hard mask to a stream of oxidizing gas in the reactor prior to or during said etch step in order to oxidize the surface of the hard mask, and thereby slow down an etch rate of the hard mask.

21. The method of claim 13 wherein:  
said selecting step includes placing a hard mask (1) which has been or (2) which can be oxidized.

22. The method of claim 13 including the step of:  
providing energy to the reactor in order to increase a rate of oxidation of the hard mask in order to slow down the rate of erosion of the hard mask.

23. (Amended) The method of claim 22 wherein :

said step of providing energy causes [the substrate] a workpiece in the reactor to be heated to a temperature in the range of from about 80°C to about 300°C.

24. The method of claim 13 including the step of:

oxidizing the hard mask either prior to or during the processing step.

25. (Amended) A method for [containment of] minimizing critical dimension growth of [a] the width of features located on a [wafer] workpiece including the steps of:

selecting a workpiece [substrate] with a hard mask deposited over a layer to be etched, which hard mask is comprised of [which comprises] at least one of titanium, titanium compounds, aluminum, aluminum compounds, tantalum, tantalum compounds, tungsten, tungsten compounds, cobalt, cobalt compounds, molybdenum, and molybdenum compounds[, over a layer to be etched into a reactor]; and

processing the workpiece [layer] in the reactor using an etch step and using the hard mask to minimize critical dimension growth of the features on the layer.

26. (Amended) A method for [containment of] minimizing critical dimension growth of [a] the width of features located on a [substrate] workpiece including the steps of:

depositing on a substrate workpiece and over a layer to be etched a hard mask comprising at least one of a reactive metal, an oxide of a reactive metal, a nitride of a reactive metal, a fluoride of a reactive metal, a boride of a reactive metal, and a carbide of a reactive metal; and

processing the [layer] workpiece in the reactor using an etch step and using the hard mask to minimize critical dimension growth of the width of features on the layer.

27. The method of claim 26 wherein:

said hard mask is selected from a material having a low sputter yield.

28. (Amended) A method for [containment of] minimizing critical dimension growth of [a] the width of features located on a [substrate] workpiece including the steps of:

depositing on a [substrate] workpiece and over a layer to be etched a hard mask, wherein said hard mask has at least one of a low sputter yield and a low reactivity to the etch chemistry of an etch process; and

processing the [layer] workpiece in the reactor using the said etch chemistry in order to etch the layer and using the hard mask to minimize critical dimension growth of the features on the layer.

29. (Amended) A method for [containment of] minimizing critical dimension growth of [a] the width of features located on a [substrate] workpiece including the steps of: depositing on a [substrate] workpiece and over a layer to be etched, a hard mask which comprises at least one of titanium, titanium compounds, aluminum, aluminum compounds, tantalum, tantalum compounds, tungsten, tungsten compounds, cobalt, cobalt compounds, molybdenum, and molybdenum compounds; and processing the workpiece [layer] in the reactor using an etch step and using the hard mask to minimize critical dimension growth of the features on the layer.

30. (Amended) A method of [containment of] minimizing critical dimension growth of [a] the width of features located on a [wafer] workpiece including the steps of: selecting a workpiece [substrate] with a hard mask consisting of one of a reactive metal, an oxide of a reactive metal, a nitride of a reactive metal, a fluoride of a reactive metal, a boride of a reactive metal, and a carbide of a reactive metal, and a compound comprising any combination of an oxide, a fluoride, a nitride, a carbide, and a boride of a reactive metal, deposited over a layer to be etched; and processing the workpiece [layer] in the reactor using an etch step and using the hard mask to minimize critical dimension growth of the features on the layer.

31. The method of claim 30 wherein:  
said selecting step includes selecting a substrate having a hard mask which consists of one of titanium, titanium compounds, aluminum, aluminum compounds, tantalum, tantalum compounds, tungsten, tungsten compounds, cobalt, cobalt compounds, molybdenum, and molybdenum compounds.

32. (Amended) The method of claim 30 including the step of:  
said selecting step includes selecting a hard mask consisting of a reactive metal;  
and  
exposing the hard mask to a stream comprising of at least one of oxygen, nitrogen, fluorine, boron, carbon, and ions or radicals of oxygen, ions or radicals of nitrogen, ions or

radicals of fluorine, ions or radicals of boron, and ions or radicals of carbon in the reactor prior to or during said etch step.

33. The method of claim 30 wherein:

said selecting step includes selecting a substrate with a hard mask, which hard mask is comprised of a metal with a low sputtering yield.

34. The method of claim 30 including the step of:

providing energy to the reactor in order to increase a rate of oxidation of the hard mask in order to slow down the rate of erosion of the hard mask.

35. The method of claim 13 wherein:

said selecting step includes selecting a substrate wherein said hard mask comprises at least one of a reactive metal, an oxide of a reactive metal, a nitride of a reactive metal, a fluoride of a reactive metal, a carbide of a reactive metal, a boride of a reactive metal or some combination of a reactive metal.

36. The method of claim 1 including the step of:

using the etched substrate to fabricate one of a semiconductor chip, a magnetic head, and a flat panel display.

37. The method of claim 1 wherein:

said selecting step includes a hard mask comprised of at least one of a reactive metal and a compound of a reactive metal; and

said selecting step further includes selecting a hard mask comprised of at least one of titanium, aluminum, tantalum, tungsten, cobalt, molybdenum, copper, nickel, iron, and compounds of at least one of titanium, aluminum, tantalum, tungsten, cobalt, molybdenum, copper, nickel, and iron.

38. The method of claim 1 wherein:

said selecting step includes a hard mask comprised of at least one of a reactive metal and a compound of a reactive metal, and said compound comprises at least one of an oxide, a nitride, a fluoride, a boride, and a carbide of a reactive metal, and any combination of an oxide, a nitride, a fluoride, a boride, and a carbide of a reactive metal.

39. The method of claim 1 wherein:

said selecting step includes a hard mask comprised of at least one of a reactive metal and a compound of a reactive metal, and said compound comprises any compounds formed by exposing a reactive metal to ions or radicals of at least one of oxygen, nitrogen, fluorine, boride, carbon, and any combination of said gases.

40. The method of claim 1 wherein:

said selecting step includes a hard mask comprised of at least one of a reactive metal and a compound of a reactive metal; and

said selecting step includes selecting a hard mask consisting of one of titanium, aluminum, tantalum, tungsten, cobalt, molybdenum, copper, iron, nickel, and compounds of one of titanium, aluminum, tantalum, tungsten, cobalt, molybdenum, copper, iron, and nickel.

41. The method of claim 38 wherein the processing step operates at one of below atmospheric pressure, atmospheric pressure, and above atmospheric pressure.

#### Remarks

A certificate of mailing is affixed hereto in accordance with 37 C.F.R. §1.8(a).


Any additional fees due for this case can be charged toward our Deposit Account #06-1325.

Continued examination and allowance of the above case is requested.

Respectfully submitted,

Date: October 19, 2000

By: \_\_\_\_\_

  
Sheldon R. Meyer  
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**METHOD FOR USING A HARD MASK  
FOR CRITICAL DIMENSION GROWTH CONTAINMENT**

**Inventors: Stephen P. DeOrnellas  
Leslie G. Jerde  
Alfred Cofer**

**Field of the Invention:**

The present invention is directed to a method for minimizing and containing the critical dimension growth of a feature on a semiconductor wafer and any other product, such as for example, the magnetic head for a disk drive and a flat panel display, which could be constructed using semiconductor processing techniques.

**Background of the Invention:**

The critical dimension (CD) of a feature on a semiconductor wafer, or any product fabricated using semiconductor processing techniques, is a width of that feature. The pitch is generally defined as a critical dimension plus the distance to the next feature.

For semiconductor process methods using etch techniques, lithographic masking layers, such as for example photoresist layers, can be formed on top of the material to be etched. Photoresist layers define the desired features, masking the portion of underlying layer which is not to be etched, and leaving exposed the portion to be etched. During the etching process, materials from a portion of the layer which is etched, as well as compounds formed by various combinations of the etchant gases, the lithographic mask, and the materials of the layer to be etched, can tend to coat the sides of the desired feature, and the lithographic mask, and thereby increase the critical dimension of the feature beyond that defined immediately under the lithographic mask. Such growth of the critical dimension can disadvantageously diminish

the space between the features and thereby adversely affect the functionality of the features.

As is known in the art, lithographic masks can include by way of example only, (i) soft masks such as photoresist masks, e-beam resist masks, x-ray resist masks, and syncrotron particle acceleration resist masks, and (ii) hard masks, such as metals and oxides of metals such as silicon dioxide ( $\text{SiO}_2$ ). However, such soft and hard masks have not been found to be particularly useful in controlling the critical dimension growth.

Accordingly, there is a need to provide a semiconductor processing methodology which allows for the desired features to be appropriately etched without causing a growth of the critical dimension of the feature during the etching process.

#### Summary of the Invention:

The present invention provides for a methodology which allows for etching the features while controlling or minimizing the growth of the critical dimension of the feature during the etching process. The method is useful for fabricating semiconductor wafers in order to produce chip products, magnetic heads for disk drives, and flat panel displays, by way of example only.

The method for critical dimension growth containment includes placing a wafer with a hard mask comprised of a reactive metal, deposited over a layer to be etched in a reactor and etching the wafer in the reactor. The placing step further includes placing a hard mask which is comprised of a reactive metal or an oxide, nitride, fluoride, carbide, boride, or some combination of an oxide, nitride, fluoride, carbide, and/or boride of a reactive metal. Such combination could include, by way of example only, an oxinitride, oxiboride, oxifluoride or



oxycarbide, of a reactive metal or any other combination or compound formed by exposing a reactive metal to ions or radicals of any combinations of oxygen, nitrogen, fluorine, boride, and/or carbon.

5 The placing step further includes placing a wafer having a hard mask which is comprised of one of titanium, aluminum, tantalum, tungsten, cobalt, or molybdenum, or an oxide, nitride fluoride carbide or boride of said reactive metals.

10 The hard mask could include other reactive metals such as copper, iron and nickel and their compounds.

10 The method also includes exposing a hard mask to a stream of oxidizing gas such as oxygen, nitrogen, fluorine, boron or carbon in the reactor prior to or during the etch step in order to form a compound with the reactive metal.

15 The method also includes exposing a hard mask to an ion or radical of oxygen, nitrogen, fluorine, boron or carbon in the reactor prior to or during the etch step in order to form an oxide, a nitride, a fluoride, a boride or a carbide or some combination of the preceding on the reactive metal.

20 The hard mask can also include any materials that are compatible with semiconductor fabrication processes, and semiconductor manufacturing tools and equipment which have the characteristics described herein.

25 The invention further includes selecting a hard mask which has or can develop an oxide, nitride, fluoride, carbide, or boride, or some combination of a reactive metal.

In another aspect of the invention, the method includes increasing the rate that one of an oxide, a nitride, a fluoride, a boride or a carbide forms on the hard mask in order to slow down the rate of erosion of the hard mask.

The invention further includes selecting a hard mask that is comprised of a metal which has a low sputter yield.

A further aspect of the present invention is to provide a method for containing critical dimension growth during an etching process including the step for placing a wafer or other substrate, for making by way of example only, a semiconductor product, a magnetic head or a flat panel display, with a hard mask disposed over a layer to be etched in a reactor, wherein the hard mask has at least one of a low sputter yield and a low reactivity to the etch chemistry of the etch process.

Accordingly, it is an object of the present invention to contain, control and minimize the growth of the critical dimension of a feature being etched.

It is still a further object of the present invention to perform the methodology of controlling and minimizing the critical dimension growth of a feature during an etch process, whether the process be conducted at low (below atmospheric) pressure, atmospheric pressure, or high (above atmospheric) pressure.

Other objects, advantages and features of the invention will be described herein and evidenced in the claims and figures.

#### **Brief Description of the Figures**

Fig. 1 depicts a schematical representation of a side elevational view of a wafer with a starting photoresist pattern placed over a hard mask, with the hard mask placed over the material to be etched.

Fig. 2 depicts a schematical representation similar to Fig. 1 which has been etched in order to define the hard mask layer.

Fig. 3 depicts a feature similar to Fig. 2 which has been etched to define the pattern in the material lying under the hard mask.

Fig. 4 depicts a schematical representation of an etch reactor wherein the method of the present invention can be carried out.

**Detailed Description of the Preferred Embodiment**

5           The method of the present invention can be performed in an etch reactor such as the etch reactor depicted in Fig. 4. It is to be understood that other reactors including but not limited to other etch reactors can be used and be within the spirit and scope of the invention.

10           The etch reactor of Fig. 4 is identified by the number 20 and is configured as a multi-frequency, tri-electrode reactor. The etching apparatus 20 includes a housing 22 and an etching chamber 24. A wafer 26 is positioned on a chuck incorporated into a bottom electrode 28. The chamber 24 further includes a side peripheral electrode 30 and an upper electrode 32. In a preferred embodiment, the side peripheral electrode 30 can be grounded or allowed to establish a floating potential as a result of the plasma developed in the chamber 24. The upper electrode 32 is generally grounded, but could also be designed to have a floating electrical potential. In typical operation, both the side peripheral electrode 30 and the upper electrode 32 are grounded as shown in Fig. 4.

20           Preferably two AC power supplies, first power supply 34 and a second power supply 36, are connected to the bottom electrode 28 through an appropriate circuitry 38, which can include by way of example only, matching networks and a combiner. Further a controller 40 controls the sequencing of the first and second AC power supplies 34, 36. Typically for this particular example only, the first power supply 34 operates in the kilohertz range and is optimally provided at about 450 KHz, and typically in the range of less than 500 KHz. The second power supply 36 operates in the megahertz range, and typically

operates at about 13.56 MHz, although other frequencies about above 1 MHz and also multiples of 13.56 MHz can be used with the present invention. The power supply 34 is powered at 200 watts and the second power supply 36 is powered at 500 watts for this example. Ion  
5 energy increases towards the kilohertz range while the ion density increases towards the megahertz range.

Additionally, reactor 20 includes gas inlet head 42 and a gas outlet port 44. Further, and preferably, the chuck 28 is heated so that a wafer positioned thereon is itself heated in the range of about 80°C  
10 to about 300°C during the process.

The growth in the critical dimension is attributable to the deposit of etched materials, mask materials, and/or compounds of etched materials, mask materials, and/or process gases on the sidewalls of the feature being etched and on the soft and/or hard masks. By way of  
15 example only, in a reactor for etching platinum with chlorine gas, materials which can stick to the sidewalls generally include platinum dichloride ( $\text{PtCl}_2$ ), a platinum trichloride ( $\text{PtCl}_3$ ), and/or other compounds. It is to be understood that the present process can be used more favorably for etching films comprised of platinum (Pt), copper (Cu),  
20 iridium (Ir), iridium dioxide ( $\text{IrO}_2$ ), lead zirconium titanate (PZT), ruthenium (Ru), ruthenium dioxide ( $\text{RuO}_2$ ), barium strontium titanate (BST), and bismuth strontium tantalate (Y-1 or SBT). These materials being etched are either metals or compounds which are of low volatility. Still other films and other semiconductor and non-semiconductor  
25 processes can benefit from this method.

Figs. 1-3 depict various stages of the inventive etch method using the reactor of Fig. 4. Fig. 1 represents a schematical representation of a scanning electron micrograph (SEM). In Fig. 1, the discrete upright structures represent the lithographic mask (a soft mask and in particular

a photoresist mask in this example) 50 which is patterned upon a hard mask 52 which has not yet been etched. The hard mask 52 has been deposited on layer 54, which is the material to be ultimately etched. Layer or film 54 is deposited on substrate 56.

In the embodiment of Fig. 1, the lithographic mask (soft mask) 50 is positioned on a hard mask 52, which hard mask is comprised of titanium nitride (TiN). The hard mask 52 is deposited on the layer 54 to be etched which in this embodiment is platinum (Pt). Layer 54 is deposited over a substrate 56 which can include, for example, silicon. The first step in the process is to etch the hard mask 52 into the desired pattern represented by the photoresist mask 50. The result of this process can be seen in Fig. 2. Fig. 3 depicts a representation where the platinum layer has been over-etched. Table 1 below records the changes in dimension in profile, pitch, feature, and space for the above four figures, where the pitch is equal to the feature dimension plus the space dimension. The change value is measured relative to the feature dimension of Fig. 1.

**Table 1**  
**Pt Etch Process with Over-Etch**  
**0.025 $\mu$  CD gain with 79° profile (CD)**

	Profile	Pitch	Feature	Space	Change
Starting resist mask layer CD (Fig. 1)	79.2°	0.564 $\mu$	0.307 $\mu$	0.257 $\mu$	-
Starting TiN mask layer CD (Fig. 2)	66.7°	0.557 $\mu$	0.317 $\mu$	0.240 $\mu$	+0.010 $\mu$
Pt layer CD (Fig. 3)	78.9°	0.555 $\mu$	0.332 $\mu$	0.227 $\mu$	+0.025 $\mu$

The operating parameters for Table 1 using the reactor of Fig. 4 are as follows:

Pressure: 1 to 50 millitorr  
MHz Power: 110 to 1500 watts  
KHz Power: 0 to 500 watts  
Total Flow Rate: 10 to 500 SCCM  
HBR Flow Rate: 0 to 200 SCCM  
CL<sub>2</sub> Flow Rate: 0 to 200 SCCM  
O<sub>2</sub> Flow Rate: 0 to 200 SCCM

A similar platinum process yielded no CD gain and an 84° profile. The starting material for the hard mask was titanium. Dimensional features for this etching process are shown below in Table 2. The etching was allowed to proceed to over-etch. The operating parameters for this particular process are in accordance with those of Table 1. Table 2 demonstrates that the invention allows the critical dimension to be held steady, without any substantial growth during the etch process.

**Table 2**  
**Pt Etch Process with Over-Etch**  
**0.00μ CD gain with 84° profile**

	Profile	Pitch	Feature	Space	Change
Starting resist mask layer CD	79.2°	0.564μ	0.307μ	0.257μ	-
Starting Ti mask layer CD	66.7°	0.557μ	0.317μ	0.240μ	+0.010 μ
Pt layer CD	84°	0.555μ	0.310μ	0.254μ	+0.003 μ

Generalizing from the above, the invention includes a method for containing critical dimension growth of a feature located on a wafer during an etch process wherein the wafer includes a hard mask comprised of a reactive metal or the oxide, nitride, fluoride, boride, or carbide, and/or combination thereof, of a reactive metal deposited over a layer to be etched. The oxide, nitride, fluoride, boride or carbide or combination thereof can be either (i) deposited as a layer, or (ii) formed in situ by exposing the reactive metal to a stream of oxygen, nitrogen, fluorine, boron or carbon and/or ions or radicals of the same either prior to or during the etch process. The hard mask layer thus acts as a self-passivation layer. In general, the class of reactive metals which are most appropriate of the present invention include titanium (Ti), aluminum (Al), and tantalum (Ta). Other reactive metals could include copper (Cu), tungsten (W), iron (Fe), nickel (Ni), cobalt (Co), and molybdenum (Mo). The most appropriate oxides and nitrides are titanium oxide ( $\text{TiO}_2$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ), titanium nitride (TiN), tantalum pentoxide ( $\text{Ta}_2\text{O}_5$ ), and tantalum nitride (TaN). Metal analogs of fluorides, borides, and carbides are also appropriate.

Other metals which are reactive and readily form oxides, nitrides, fluorides, borides or carbides come within the spirit and scope of the invention. Further, these metals preferably have a low sputtering yield with etchants which further enhances critical dimension growth containment. Table 3 below compares the sputtering yield of these materials against platinum and silicon dioxide for argon ion bombardment at 600 electron volts (eV).

**Table 3**

	Bombarding argon ion energy in 600 eV
Pt	1.56
SiO <sub>2</sub>	1.34
Ti	0.58
TiO <sub>2</sub>	0.96
Al	1.24
Al <sub>2</sub> O <sub>3</sub>	0.18
Ta	0.62
Ta <sub>2</sub> O <sub>5</sub>	0.15
TiN	1.60
W	0.62

Adding oxidants such as oxygen to the process gas and in particular with respect to a hard mask comprised of titanium or aluminum causes the formation of an oxide on the hard mask resulting in less erosion of the hard mask and a minimization of the critical dimension growth. This oxidation of the metal results in less sputtering, which means that the hard mask itself can be thinner. Similar advantages occur with the formation of nitrides, carbides, and/or borides, and/or some combinations thereof of reactive metals.

Accordingly, it can be seen that reactive metals which form skins of oxides, nitrides, fluorides, borides and/or carbides are advantageous to the method of the invention. Further, increasing the temperature at the surface of the wafer, in preferably the range of 80° Centigrade to 300° Centigrade, increases the rate of oxidation which slows the erosion rate of the hard mask. Again, similar results are observed with oxides, nitrides, fluorides, carbides, and/or borides, and/or combinations thereof, of reactive metals.



Thus, from the above, it can be seen that the hard mask selected from a reactive metal or selected from an appropriate oxide, nitride, fluoride, carbide, boride, or some combination thereof, of a reactive metal, and which material has a favorably low sputter yield, is an appropriate material for the hard mask of the present invention. Such method is particularly important for controlling critical dimension growth for a submicron feature and in particular for features which have a pitch of less than  $0.5\mu$ .

Further, it is to be understood that for the above preferred hard mask, a low sputter yield, and a low chemical reactivity of the mask with the process gases is a consideration. For example, from Table 3, a quick review would tend to suggest that titanium with a sputter yield of 0.58 would be a more appropriate hard mask than titanium oxide with a sputter yield of 0.96. However, with etchant gas of chlorine, the titanium is more reactive than the titanium oxide and thus, the titanium oxide could provide for better critical dimension growth containment even though it has a higher sputter yield.

#### Industrial Applicability

From the above, it can be seen that the method of the invention is useful for performing an etch or other semiconductor process step while containing critical dimension growth in order to develop features for submicron dimension products.

Other features, aspects and objects of the invention can be obtained from a review of the figures and the claims.

It is to be understood that other embodiments of the invention can be developed and fall within the spirit and scope of the invention as claimed.

We claim:

1. A method for containment of critical dimension growth of a feature located on a substrate including the steps of:

5 selecting a substrate with a hard mask comprised of a reactive metal deposited over a layer to be etched; and processing the layer in a reactor.

2. The method of claim 1 wherein:

10 said selecting step includes selecting a substrate having a hard mask which hard mask comprises of one of titanium, aluminum, and tantalum.

3. The method of claim 1 including the step of:

15 exposing the hard mask to a stream of oxidizing gas in the reactor prior to or during said etch step.

4. The method of claim 1 including the step of:

20 exposing the hard mask to an oxidizing stream comprising of one of oxygen, nitrogen, fluorine, boron, and carbon gas, and any combination of oxygen, nitrogen, fluorine, boron, and carbon gas, in the reactor prior to or during said etch step.

5. The method of claim 1 wherein :

25 said selecting step includes selecting a substrate with a lithographic layer covering the hard mask into the reactor.

6. The method of claim 1 wherein:

said selecting step includes selecting a substrate having a hard mask which is readily oxidizable.

7. The method of claim 1 wherein:

5           said selecting step includes selecting a substrate with a hard mask, which hard mask is comprised of a metal with a low sputtering yield.

8. The method of claim 1 including the step of:

10           exposing the hard mask to a stream of oxidizing gas in the reactor prior to or during said etch step in order to oxidize the surface of the hard mask and thereby slow down an etch rate of the hard mask.

9. The method of claim 1 wherein:

15           said selecting step includes selecting a hard mask (1) on which has been or (2) on which can be developed at least one of an oxide, nitride, fluoride, boride and carbide.

10. The method of claim 1 including the step of:

20           providing energy to the reactor in order to increase a rate of oxidation of the hard mask in order to slow down the rate of erosion of the hard mask.

11. The method of claim 10 wherein :

25           said step of providing energy causes the substrate in the reactor to be heated to from about 80°C to about 300°C.

12. The method of claim 1 including the step of:

oxidizing the hard mask either prior to or during the processing step.

5           13. A method for containment of critical dimension growth of a feature located on a substrate including the steps of:

          selecting a substrate with a hard mask deposited over a layer to be etched, wherein said hard mask has a low sputter yield and a low reactivity to the etch chemistry of an etch process; and

10           processing the layer in a reactor using the said etch chemistry.

          14. The method of claim 13 wherein:

          said selecting step includes selecting a substrate wherein said hard mask is comprised of a reactive metal.

15           15. The method of claim 13 wherein:

          said selecting step includes selecting a substrate having a hard mask which is comprising at least one of titanium, aluminum, tantalum, tungsten, cobalt, and molybdenum.

20           16. The method of claim 13 including the step of:

          exposing the hard mask to a stream of oxidizing gas in the reactor prior to or during said processing step.

          17. The method of claim 13 including the step of:

25           exposing the hard mask to a stream consisting of one of oxygen, nitrogen, fluorine, boron, and carbon and any combination of oxygen, nitrogen, fluorine, boron and carbon.

          18. The method of claim 13 wherein :

said selecting step includes selecting a substrate with a lithographic layer covering the hard mask.

19. The method of claim 13 wherein:

5       said selecting step includes selecting a substrate having a hard mask which is readily oxidizable.

20. The method of claim 13 including the step of:

10       exposing the hard mask to a stream of oxidizing gas in the reactor prior to or during said etch step in order to oxidize the surface of the hard mask, and thereby slow down an etch rate of the hard mask.

21. The method of claim 13 wherein:

15       said selecting step includes placing a hard mask (1) which has been or (2) which can be oxidized.

22. The method of claim 13 including the step of:

20       providing energy to the reactor in order to increase a rate of oxidation of the hard mask in order to slow down the rate of erosion of the hard mask.

23. The method of claim 22 wherein :

25       said step of providing energy causes the substrate in the reactor to be heated to from about 80°C to about 300°C.

24. The method of claim 13 including the step of:

oxidizing the hard mask either prior to or during the processing step.

25. A method for containment of critical dimension growth of a feature located on a wafer including the steps of:

5 selecting a substrate with a hard mask which comprises at least one of titanium, titanium compounds, aluminum, aluminum compounds, tantalum, tantalum compounds, tungsten, tungsten compounds, cobalt, cobalt compounds, molybdenum, and molybdenum compounds, over a layer to be etched into a reactor; and processing the layer in the reactor.

10 26. A method for containment of critical dimension growth of a feature located on a substrate including the steps of:

15 depositing on a substrate over a layer to be etched a hard mask comprising at least one of a reactive metal, an oxide of a reactive metal, a nitride of a reactive metal, a fluoride of a reactive metal, a boride of a reactive metal, and a carbide of a reactive metal; and processing the layer in the reactor.

20 27. The method of claim 26 wherein:  
said hard mask is selected from a material having a low sputter yield.

28. A method for containment of critical dimension growth of a feature located on a substrate including the steps of:

25 depositing on a substrate over a layer to be etched a hard mask, wherein said hard mask has at least one of a low sputter yield and a low reactivity to the etch chemistry of an etch process; and processing the layer in the reactor using the said etch chemistry.

29. A method for containment of critical dimension growth of a feature located on a substrate including the steps of:

depositing on a substrate over a layer to be etched, a hard mask which comprises at least one of titanium, titanium compounds, aluminum, aluminum compounds, tantalum, tantalum compounds, tungsten, tungsten compounds, cobalt, cobalt compounds, molybdenum, and molybdenum compounds; and processing the layer in the reactor.

30. A method of containment of critical dimension growth of a feature located on a wafer including the steps of:

selecting a substrate with a hard mask consisting of one of a reactive metal, an oxide of a reactive metal, a nitride of a reactive metal, a fluoride of a reactive metal, a boride of a reactive metal, and a carbide of a reactive metal, and a compound comprising any combination of an oxide, a fluoride, a nitride, a carbide, and a boride of a reactive metal, deposited over a layer to be etched; and processing the layer in the reactor.

31. The method of claim 30 wherein:

said selecting step includes selecting a substrate having a hard mask which consists of one of titanium, titanium compounds, aluminum, aluminum compounds, tantalum, tantalum compounds, tungsten, tungsten compounds, cobalt, cobalt compounds, molybdenum, and molybdenum compounds.

32. The method of claim 30 including the step of:

selecting a hard mask consisting of a reactive metal; and

exposing the hard mask to a stream comprising of at least one of oxygen, nitrogen, fluorine, boron, carbon, and ions or radicals of oxygen, ions or radicals of nitrogen, ions or radicals of fluorine, ions or radicals of boron, and ions or radicals of carbon in the reactor prior to or during said etch step.

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33. The method of claim 30 wherein:

said selecting step includes selecting a substrate with a hard mask, which hard mask is comprised of a metal with a low sputtering yield.

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34. The method of claim 30 including the step of:

providing energy to the reactor in order to increase a rate of oxidation of the hard mask in order to slow down the rate of erosion of the hard mask.

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35. The method of claim 13 wherein:

said selecting step includes selecting a substrate wherein said hard mask comprises at least one of a reactive metal, an oxide of a reactive metal, a nitride of a reactive metal, a fluoride of a reactive metal, a carbide of a reactive metal, a boride of a reactive metal or some combination of a reactive metal.

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36. The method of claim 1 including the step of:

using the etched substrate to fabricate one of a semiconductor chip, a magnetic head, and a flat panel display.

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37. The method of claim 1 wherein:



said selecting step includes a hard mask comprised of at least one of a reactive metal and a compound of a reactive metal; and

said selecting step further includes selecting a hard mask comprised of at least one of titanium, aluminum, tantalum, tungsten, cobalt, molybdenum, copper, nickel, iron, and compounds of at least one of titanium, aluminum, tantalum, tungsten, cobalt, molybdenum, copper, nickel, and iron.

38. The method of claim 1 wherein:

said selecting step includes a hard mask comprised of at least one of a reactive metal and a compound of a reactive metal, and said compound comprises at least one of an oxide, a nitride, a fluoride, a boride, and a carbide of a reactive metal, and any combination of an oxide, a nitride, a fluoride, a boride, and a carbide of a reactive metal.

39. The method of claim 1 wherein:

said selecting step includes a hard mask comprised of at least one of a reactive metal and a compound of a reactive metal, and said compound comprises any compounds formed by exposing a reactive metal to ions or radicals of at least one of oxygen, nitrogen, fluorine, boride, carbon, and any combination of said gases.

40. The method of claim 1 wherein:

said selecting step includes a hard mask comprised of at least one of a reactive metal and a compound of a reactive metal; and

said selecting step includes selecting a hard mask consisting of one of titanium, aluminum, tantalum, tungsten, cobalt, molybdenum, copper, iron, nickel, and compounds of one of titanium, aluminum, tantalum, tungsten, cobalt, molybdenum, copper, iron, and nickel.

41. The method of claim 38 wherein the processing step operates at one of below atmospheric pressure , atmospheric pressure, and above atmospheric pressure.

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**ABSTRACT:**

A method for containing the critical dimension growth of the feature on a semiconductor substrate includes placing a substrate with a hard mask comprised of a reactive metal or an oxidized reactive metal in a chamber and etching the wafer. The method further includes using a hard mask which has a low sputter yield and a low reactivity to the etch chemistry of the process.

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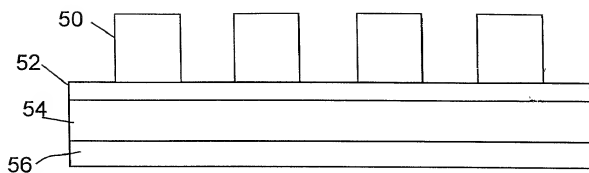


Fig. 1

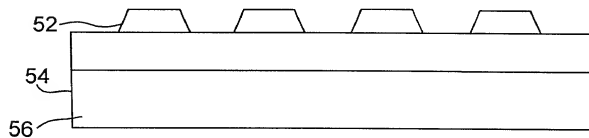


Fig. 2

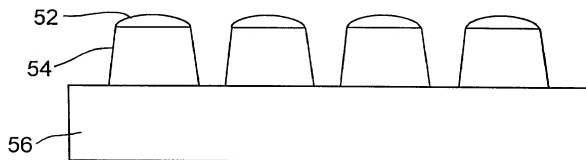


Fig. 3

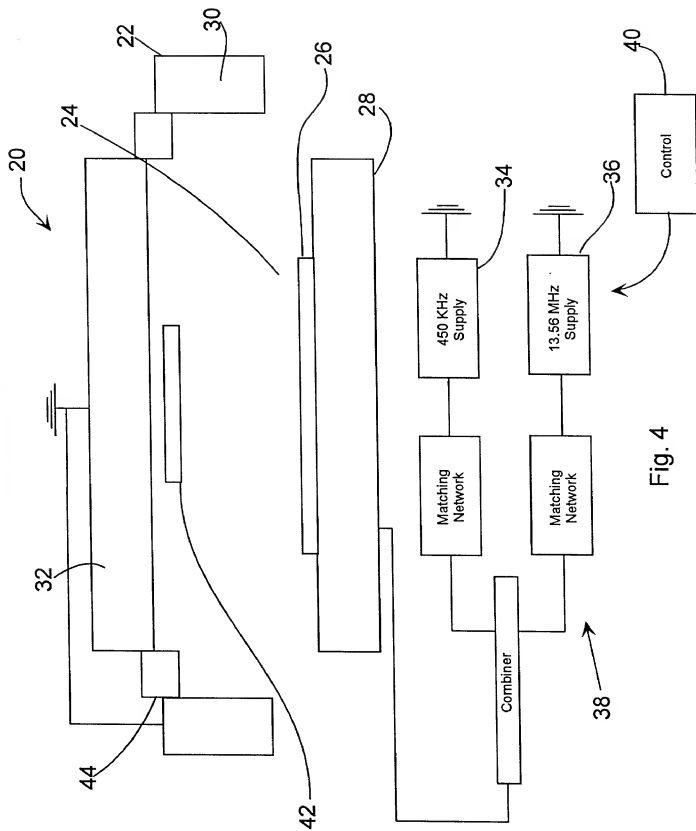


Fig. 4

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application ) PATENT APPLICATION  
)  
Inventor(s): Stephen P. DeOrnellas, et al. )  
)  
SC/Serial No.: 09/009,369 )  
)  
Filed: January 20, 1998 )  
)  
Title: METHOD FOR USING A HARD MASK FOR )  
CRITICAL DIMENSION GROWTH CONTAINMENT )  
\_\_\_\_\_ )

DECLARATION FOR PATENT APPLICATION

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name; I believe that I am the original, first and sole inventor (if one name is listed below), first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

METHOD FOR USING A HARD MASK FOR  
CRITICAL DIMENSION GROWTH CONTAINMENT

the specification of which (check applicable ones):

\_\_\_\_\_ is filed herewith;  
  X   was filed with the above-identified "Filed" date and "SC/Serial No."  
\_\_\_\_\_ was amended on (or amended through) \_\_\_\_.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose information which is material to the examination of the application in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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(3) Inventor's signature: Alfred Cofer

(3) Date: 3/9/98

\*\*\*\*\*

Title 37, Code of Federal Regulations, §1.56

**SECTION 1.56. DUTY TO DISCLOSE INFORMATION  
MATERIAL TO PATENTABILITY**

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is cancelled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is cancelled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§1.97(b)-(d) and 1.98.\* However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

- (1) prior art cited in search reports of a foreign patent office in a counterpart application, and
- (2) the closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made of record in the application, and

(1) It establishes, by itself or in combination with other information, a *prima facie* case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the applicant takes in:

(i) Opposing an argument of unpatentability relied on by the Office; or

(ii) Asserting an argument of patentability.

A *prima facie* case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

(1) Each inventor named in the application;

(2) Each attorney or agent who prepares or prosecutes the application; and

(3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent, or inventor.

\* §§1.97(b)-(d) and 1.98 relate to the timing and manner in which information is to be submitted to the Office.

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